Can vital signs recorded in patients' homes aid decision making in emergency care?

A Scoping Review

Hamza, Muhammad; Alsma, Jelmer; Kellett, John; Brabrand, Mikkel; Christensen, Erika F; Cooksley, Tim; Haak, Harm R; Nanayakkara, Prabath W B; Merten, Hanneke; Schouten, Bo; Weichert, Immo; Subbe, Christian P

Published in:
Resuscitation plus

DOI (link to publication from Publisher):
10.1016/j.resplu.2021.100116

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

Resuscitation Plus

journal homepage: www.journals.elsevier.com/resuscitation-plus

Review

Can vital signs recorded in patients' homes aid decision making in emergency care? A Scoping Review

Muhammad Hamza[a], *Jelmer Alsma*[b], *John Kellett*[c], *Mikkel Brabrand*[d], *Erika F. Christensen*[e], *Tim Cooksley*[f], *Harm R. Haak*[g], *Prabath W.B. Nanayakkara*[h], *Hanneke Merten*[i], *Bo Schouten*[i], *Immo Weichert*[j], *Christian P. Subbe*[k,*]

[a] *Department of Acute Medicine, Ysbyty Gwynedd Hospital, Bangor, United Kingdom*
[b] *Department of Internal Medicine, Erasmus University Medical Center, Rotterdam, The Netherlands*
[c] *Department of Emergency Medicine, Hospital of South West Jutland, Esbjerg, Denmark*
[d] *Department of Emergency Medicine, Odense University Hospital, Odense, Denmark*
[e] *Center for Prehospital and Emergency Research, Clinic of Internal and Emergency Medicine, Aalborg University Hospital, Aalborg, Denmark*
[f] *Department of Acute Medicine, University Hospital of South Manchester, Manchester, United Kingdom*
[g] *Department of Internal Medicine, Division of General Internal Medicine, Maastricht University Medical Center, Maastricht, The Netherlands*
[h] *Section of Acute Medicine, Department of Internal Medicine, Amsterdam Public Health research institute, Amsterdam University Medical Center, location VU University Medical Center, Amsterdam, The Netherlands*
[i] *Department of Public and Occupational Health, Amsterdam Public Health research institute, Amsterdam University Medical Center, location VU University Medical Center, Amsterdam, The Netherlands*
[j] *Department of Acute Medicine, Ipswich Hospital, East Suffolk and North Essex NHS Foundation Trust, Ipswich, United Kingdom*
[k] *School of Medical Sciences, Bangor University, Bangor, United Kingdom*

Abstract

Aim: Use of tele-health programs and wearable sensors that allow patients to monitor their own vital signs have been expanded in response to COVID-19. We aimed to explore the utility of patient-held data during presentation as medical emergencies.

Methods: We undertook a systematic scoping review of two groups of studies: studies using non-invasive vital sign monitoring in patients with chronic diseases aimed at preventing unscheduled reviews in primary care, hospitalization or emergency department visits and studies using vital sign measurements from wearable sensors for decision making by clinicians on presentation of these patients as emergencies. Only studies that described a comparator or control group were included. Studies limited to inpatient use of devices were excluded.

Results: The initial search resulted in 896 references for screening, nine more studies were identified through searches of references. 26 studies fulfilled inclusion and exclusion criteria and were further analyzed. The majority of studies were from telehealth programs of patients with congestive heart failure or Chronic Obstructive Pulmonary Disease. There was limited evidence that patient held data is currently used to risk-stratify the admission or discharge process for medical emergencies. Studies that showed impact on mortality or hospital admission rates measured vital signs at least daily. We identified no interventional study using commercially available sensors in watches or smart phones.

* Corresponding author at: 21 Menai Quays, Menai Bridge, LL59 5DB, United Kingdom.
E-mail addresses: goodoldhamza@gmail.com (M. Hamza), j.alsma@erasmusmc.nl (J. Alsma), kellettjg@gmail.com (J. Kellett), mikkel.brabrand@rsyd.dk (M. Brabrand), efc@rn.dk (E.F. Christensen), tim.cooksley@uhsm.nhs.uk (T. Cooksley), h.haak@mmc.nl (H.R. Haak), p.nanayakkara@amsterdamumc.nl (P.W.B. Nanayakkara), h.merten@amsterdamumc.nl (H. Merten), b.schouten1@amsterdamumc.nl (B. Schouten), immo.weichert@ipswichhospital.nhs.uk (I. Weichert), csubbe@hotmail.com (C.P. Subbe).

http://dx.doi.org/10.1016/j.resplu.2021.100116
Received 22 November 2020; Received in revised form 16 March 2021; Accepted 19 March 2021

Conclusions: Further research is needed to determine utility of patient held monitoring devices to guide management of acute medical emergencies at the patients' home, on presentation to hospital and after discharge back to the community.
Keywords: Emergency, Wearable, Vital signs, Telehealth, COVID-19

Introduction

The COVID-19 pandemic has resulted in an increase in the number of virtual wards[1] that are monitoring patients in their own home to detect deterioration and the need for hospital admission. In traditional practice the decision about the need of an individual to require admission to a hospital relies on the assessment of patients' symptoms, signs, past-medical history, diagnosis and social support at home[2–4] and a judgment of the severity of illness based on an estimated risk of deterioration in the subsequent hours and days.[5]

Abnormalities of vital signs are quantified by comparison with 'normal' measurements of healthy individuals during periods of physiological stability. Within these individuals the 'normal' measurements vary and are influenced by genetic determinants, age, sex, body composition, medications and physical condition. There is an association between the magnitude of change from a physiological normal range, the number of vital signs affected by the disease state and the frequency of adverse events.[6,7] Abnormality can be scored with generic tools that can be applied to the majority of patients such as the National Early Warning Score (NEWS).[8] However these scores can under- or overestimate risk in individual patients.[9]

In patients with chronic conditions such as chronic heart failure (CHF) or chronic obstructive pulmonary disease (COPD)[10] vital signs are often not comparable to those of healthy individuals even during times of stability. In order to assess the severity of illness of a patient with chronically abnormal vital signs clinicians might compare measurements on presentation to hospital with values derived from previous clinical encounters such as outpatient clinic visits, primary care attendances or records from previous hospital admissions but do usually not know what the patient's measurements are in their own living and working life. Patients with heart failure are likely to have chronically low pulse pressure[11] and patients with COPD often have a higher heart rate, respiratory rate and lower oxygen saturations than patients without this condition.[12] Beyond this, physiological reserve might also affect the degree of physiological abnormality in response to a disease.[13]

Knowing the values of an individual patient's vital signs during a period of relative wellness might therefore help clinicians to understand trends[14] and the degree of deviation from normal and hence the severity of illness of a patient. Individual vital signs (e.g., heart rate, heart rhythm, oxygen saturation) can easily be measured by smartwatches and mobile telephones. Smart monitoring devices allow data to be captured and interpreted by apps; connection to the internet allows data to be shared in real time with others. Currently, 49 −83% of the population of European countries and 79% of the United States use smartphones, and this number is rising.[15]

According to the Institute of Medicine, the quality of interventions can be defined in six dimensions[16]: safety, effectiveness, patient-centeredness, timeliness, efficiency, and equity. Applied to acute care we would therefore hypothesizes that wearable monitors would need to demonstrate

1. improvements in the way that risk is quantified and managed,
2. effectiveness in identifying a significant change in the physiological status of a person earlier than current methods and in real time,
3. the ability of patients to review and manage their own risk according to their preferences,
4. the capability to link into protocols that use the data to initiate more timely treatment before catastrophic deterioration in the community, and finally
5. the ability of more citizens to have access to high quality monitoring of their health.

In this review we aimed to map the literature on how measurements of vital signs taken by patients at home might inform decision-making on presentation to hospital or other emergency services and identify gaps for future research.

Methods

We performed a scoping review using Arksey and O'Malley's methodology and Levac's conceptual extension.[17,18] We followed the five-step process proposed by O'Malley's:

1. Identification of the research question: The research question was formulated through an iterative process after a cursory screening of the literature. Consensus on the search terms, inclusion of studies and themes for synthesis were achieved during conference calls between the authors. We identified two related topics for examination:

    a. Long-term monitoring: How has non-invasive vital sign monitoring been used in patients with chronic diseases to prevent unscheduled reviews in primary care, hospitalization or emergency department (ED) visits?
    b. Opportunistic utilization: How are vital sign measurements from wearable sensors utilized by clinicians on presentation to emergency services such as out-of-hours primary care services, emergency departments or acute medical units? Given that current wearable sensors are able to measure vital signs and mobility both areas were included in the search.

2. Identification of relevant studies was through relevant MESH terms: "Telemedicine" and "Wearable Electronic Devices" and "Smartphone" were combined with "Vital Signs" and "Mobility Limitation". The searches were conducted on MEDLINE, EMBASE and the Cochrane Library. The search was limited to studies published on or before March 31st 2020. The search terms that were used in the literature review are present in the appendix. The search was undertaken in March of 2020 with additional searches undertaken in October 2020 and January 2021.
3. Selection of studies:

    Inclusion criteria: Included were studies in adult patients that used non-invasive devices to measure at least one vital sign and tracked unscheduled visits to primary care, emergency

department or admission to hospital in such patients. Only interventional or observational studies with a comparator or control group were included.

Exclusion criteria: pilot or feasibility studies, conference presentations; vital sign recordings limited to inpatient settings, and studies without information about the monitoring device.

Additional searches were undertaken against a representative sample of leading brand names: a search for studies involving Apple Watch resulted in two case studies,[19,20] no studies of wearables by Fitbit, Garmin, Jawbone, Pebble, Polar and Samsung were found.

4. Charting the data: Data was extracted from each manuscript in a standardized format including information about type of study, setting, number of study subjects, clinical conditions included, nature of the device, duration of follow up, outcome measures, important patient characteristics and clinical impact.

HM undertook the primary searches and JK, JA & CSP undertook secondary searches and verified data and data extraction from the primary searches. Incongruences were discussed in online consensus meetings.

5. Collating, summarizing and reporting the results: Identified studies were grouped according to methodological and clinical themes. Results were reported in tables and summarized in the manuscript. The final manuscript was circulated twice between all authors to achieve consensus.

Results

The original search conducted in March 2020 yielded 896 potentially relevant citations. After screening 94 citations met the inclusion criteria based on title and abstract and the corresponding full text articles were procured for review. After sight of the full text 26 articles were included in the study (Fig. 1: Flow diagram). Adding 'mobility limitations' to the search resulted in no additional studies. Two studies used the same dataset with different outcome measures.[21,22]

Of the 26 studies fulfilling our inclusion criteria three originated from the US,[21–23] five from the UK,[24–28] three from Spain,[29–31] three from Italy[32–34] and one from Germany,[35] Taiwan,[36] Japan,[37] Finland,[38] Belgium,[39] Holland,[40] Australia,[41] New Zealand[42] and Denmark.[43] Three studies were multi-center trials from Europe.[44–46] 24 studies were randomized controlled trials and 2 studies were before and after comparisons.

Characteristics of the interventions are summarized in Table 1 and measurements and clinical outcomes in Table 2.

Characteristics of monitoring devices

Specified devices included the Sweetage™ wrist wearable device,[32] Intel™ health telemonitoring device,[21,22] Wrist Clinic wearable device™,[46] Motiva system™,[27,47] Honeywell Home Med™[28,25] and a Tanita device designed to measure body-composition.[37]

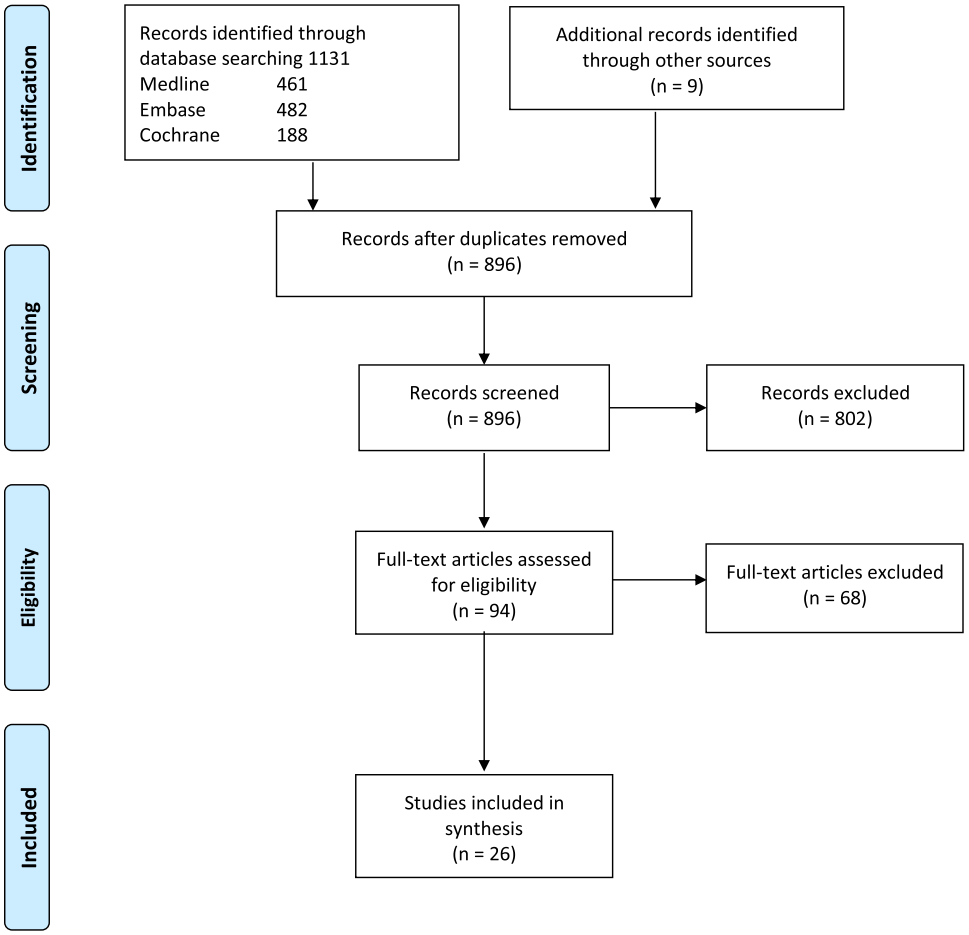

Fig. 1 – PRISMA flow diagram for the searches of the Scoping Review.

Table 1 – Study characteristics.

Author	Type of study	Country	Sampling Time	Age cut off?	Age[1]	Follow up	Comparison	n	Measurement devices	Mechanism of transmission	Patient Involvement	Mechanism of interpretation	Response to abnormalities	Interventions	Device name
Heart-failure															
Cleland (2005)	Randomized Controlled Trial	German, UK, Netherlands	August 2000-March 2002	Adult patients	67 ± 13	8 months	Telemonitoring vs Nurse Telephone support vs Usual care	424	Conventional measurement of HR, BP, weight, single lead ECG	Short range radio transmitter to Internal Modem (telephone line)	Patients measured vital signs twice daily. Patients received equipment training.	Computer algorithms would detect and notify the vital signs outside of the normal range	Instantaneous	Review of Patient's medications by nurse or General Practitioner	Automated Interactive Voice Response System
Mortara (2009)	Randomized Controlled Trial	Italy, UK, Poland	July 2002–July 2004	Patients younger than 85 years of age	60 ± 12	12 months	Telemonitoring vs Usual care	461	Non-invasive cardiorespiratory activity recorder, digital blood pressure monitor, scale. Holter Style recorder.	Data via modem	A Holter style recorder automatically measured the vital signs. Patients also measured some vital signs weekly. Patients received equipment training.	Computer algorithms would detect and notify the vital signs outside of the normal range	Instantaneous	Doctor/nurse's choice based on guidelines	Automated Interactive Voice Response System
Dar (2009)	Randomized Controlled Trial	UK	June 2006 –August 2007	Adult patients	70 ± 12	6 months	Telemonitoring vs Usual care	182	Electronic weighing scale, automated blood pressure cuff, pulse oximeter	Vital signs picked automatically by control box and relayed through Telephone	Patients measured vital signs daily. Patients received equipment training.	Monitored on weekdays by nurse/physician	Scheduled	Lifestyle and medication advice, Primary care and secondary care referral	Honeywell HomeMedTM
Domingo (2011)	Prospective intervention study with before/after comparison design	Spain	July 2007 –December 2008	Adult patients	66 ± 11	12 months	Motiva System with educational videos, motivational messages & questionnaires vs Motiva System & self-monitoring	92	Electronic weighing scale, automated blood pressure cuff	Broadband Internet	Patient measured vital signs daily. Patients received equipment training.	Realtime monitoring by medical staff who could send messages via the system	-Not reported	Educational videos, Personalized advice	Motiva system
Dendale (2011)	Randomized Controlled Trial	Belgium	April 2008 –June 2010	Adult patients	76 ± 10	6 months	Usual care vs TM	160	Electronic weighing scale, automated blood pressure cuff	Cellular Network	Patient measured vital signs daily. Patients received equipment training.	Measurements outside predefined limits for two consecutive days resulted in alert to, GP and heart failure clinic via automated email	Instantaneous	Home GP Visit	Automated Interactive Voice Response System
Vuorinen (2014)	Randomized Controlled Trial	Finland	November 2010 –August 2011	Patients younger than 90 years of age	58 ± 11	6 months	Usual care vs TM	94	Electronic weighing scale, automated blood pressure cuff	Broadband Internet	Patient measured vital signs weekly. Patients received equipment training.	Vital signs monitored daily by nurse. Patients contacted if outside normal range	Scheduled	Secondary Care referral	Motiva system
Kraai (2016)	Randomized Controlled Trial	Netherlands	December 2009 –January 2012	Adult patients	69 ± 12	9 months	Computer decision support vs TM & clinical decision support	177	Conventional devices measuring HR, BP weight, Pulse oxymetry, etc.	GPRS on a mobile phone	Patient measured vital signs daily. Patients received equipment training.	Vital signs used to generate algorithms Only those vital signs were seen by a nurse which were outside the range	Instantaneous	Discussion of symptoms and treatment with patient	
Kotooka (2018)	Randomized Controlled Trial	Japan	December 2011 –August 2013	Adult patients	67 ± 12	15 months	Usual care vs TM	181	Electronic scale with body composition meter, sphygmomanometer	Internet	Patient measured vital signs daily. Patients received equipment training.	Vital signs monitored daily by nurse from 9AM to 7 PM each day.	Scheduled	Advice, Medication adjustments, hospital admission	Karada Karte™ Tanita Health-link
Koehler (2018)	Randomized Controlled Trial	Germany	August 2013 –May 2017	Adult patients	70 ± 11	12 months	Usual care vs TM	1571	Conventional devices measuring HR, BP weight, Pulse oximeter, etc.	Cellular Network	Patient measured vital signs daily. Patients received equipment training.	Vital signs monitored daily. Computer algorithms to identify worsening	Instantaneous	Medication adjustment, Home visits, hospital admissions	ECG by Physio-Mem PM BP by A&D Company Ltd Scale by Seca SPO2 by Masimo

Table 1 *(continued)*

Author	Type of study	Country	Sampling Time	Age cut off?	Age[1]	Follow up	Comparison	n	Measurement devices	Mechanism of transmission	Patient Involvement	Mechanism of interpretation	Response to abnormalities	Interventions	Device name
Palmieri (2011)	Prospective intervention study with before/after comparison design	Italy	–	Adult patients	70 ± 10	10 months	Previous year data vs TM year data	23	blood pressure, heart rate and blood oxygen saturation	Data transmission via modem.	Patient measured vital signs daily. Patients received equipment training.	Twice weekly monitoring by doctor-nurse unit	-Not reported	–	
COPD															
De San Miguel (2013)	Randomized Controlled Trial	Australia	–	Adult patients	71 [range 54–88]	6 months	Usual care vs TM	71	Conventional devices measuring HR, BP weight, pulse oximeter etc.	Vital signs picked automatically by control box and relayed through Telephone	Patient measured vital signs daily. Patients received equipment training	Vital signs monitored daily by nurse/ physician	Scheduled	Advice, Primary care referral	Docobo Health hub
Pinnock (2013)	Randomized Controlled Trial	UK	May 2009 –March 2011	Adult patients	69 ± 8	12 months	Usual care vs TM	256	Pulse oximeter	Broadband Internet	Patient measured vital signs daily. Patients received equipment training	Vital signs monitored daily. Computer algorithms to identify worsening	Instantaneous	Rescue treatment, home visits, hospital admissions	
Pedone (2013)	Randomized Controlled Trial	Italy	–	Patients older than 65 years of age	74 ± 6	9 months	Usual care vs TM	99	Wearable device measuring vital signs (wrist watch)	Bluetooth and Cellular Telephone	Patients were not given equipment training. Vital signs were measured automatically	Vital signs monitored daily by nurse	Scheduled	Secondary care referral, hospital admission	Sweetage TM
McDowell (2015)	Randomized Controlled Trial	UK	August 2009 –January 2010	Adult patients	69 ± 7	6 months	Usual care vs TM	110	Automated blood pressure, heart rate, oximetry	Telephone line	Patient measured vital signs daily. Patients received equipment training	Vital signs monitored daily by nurse. Alerts were manually generated if there was a deviation in vital signs	Scheduled	Home visits, Emergency department referral, GP referral	Honeywell HomeMedTM
Chatwin (2016)	Randomized Crossover Trial	UK	July 2009–July 2011	Adult patients	62 ± 11	6 months	TM vs Delayed TM	72	Electronic weighing scale, automated blood pressure cuff, heart rate, oximetry	Broadband Internet	Patient measured vital signs daily. Patients received equipment training	Vital signs were monitored on week days. Measurements outside predefined limits generated an alert	Scheduled	Medication adjustments, education, GP referrals, Consultant referrals, home visits	Philips Motiva System
Segrelles Calvo (2014)	Randomized Controlled Trial	Spain	January 2010 –July 2011	Patients older than 50 years of age	75 ± 9	7 months	Usual care vs TM	60	Automated blood pressure cuff, pulse oximeter, peak flow	HR, BP communicated over telephone line	Patient measured vital signs daily. Patients received equipment training	Vital signs outside range defined by algorithm seen by a nurse	Instantaneous	Medication adjustments, home visits, secondary care referral	Automated Interactive Voice Response System
Ringbæk (2015)	Randomized Controlled Trial	Denmark	November 2013 –April 2014	Adult patients	70 ± 9	6 months	Usual care vs TM	141 (281)	spirometer, pulse oximeter, weighing scale	Internet	Pulse oximetry and weight 3×/week (first 4 weeks), then 1×/ week. Spirometry 1×/ week (first 4 weeks) then once monthly	Vital signs reviewed by nurse	Scheduled	Contact with respiratory nurse or medical specialist via video consultations	Not reported
Ho (2016)	Randomized Controlled Trial	Taiwan	December 2011 –July 2013	Adult patients	81 ± 7	6 months	Usual care vs TM	106	Conventional devices measuring HR, BP weight, Pulse oximeter etc.	Internet and Bluetooth	Patient measured vital signs daily. Patients received equipment training	Vital signs outside range defined by algorithm seen by a nurse	Instantaneous	Secondary care referrals	
Walker (2018)	Randomized Controlled Trial	UK, Estonia, Sweden, Spain, Slovenia	October 2013 –July 2015	Patients older than 60 years of age	71 [IQR 66 –76]	9 months	Usual care vs TM	312	Wearable device measuring vital signs (wristwatch)	Cellular Modem	Patients were not given equipment training. Vital signs were measured automatically	Vital signs outside range defined by algorithm seen by a nurse	Instantaneous	Medication adjustment, Secondary care referral	Wrist clinic TM

(continued on next page)

Table 1 *(continued)*

Author	Type of study	Country	Sampling Time	Age cut off?	Age[1]	Follow up	Comparison	n	Measurement devices	Mechanism of transmission	Patient Involvement	Mechanism of interpretation	Response to abnormalities	Interventions	Device name
Mixed population															
Finkelstein (2006)	Randomized Controlled Trial	USA	–	Adult patients	74 [range 60–96]	6 months	Nurse virtual care & TM vs Usual care	53	Electronic weighing scale, automated blood pressure cuff, pulse oximeter	Vital signs picked automatically by control box and relayed through Telephone	Patient measured vital signs twice weekly. Patients received equipment training	Vital signs reviewed daily by nurse/ physician	Scheduled	Virtual visits with patient	Honeywell HomeMedTM
Vitacca (2009)	Randomized Controlled Trial	Italy	April 2004 –March 2007	Adult patients	61 ± 17	12 months	TM vs Usual care	240	Pulse oximetry	Data transmission via modem.	Patient measured vital signs daily. Patients received equipment training	Vital signs were monitored on week days. Measurements outside predefined limits generated an alert	Scheduled	Secondary care referral, tele-assistance, tele-consultation	Model 2500, Nonin Medical, MN, USA
Steventon (2012)	Randomized Controlled Trial	England	May 2008 –September 2009	Adult patients	69 ± 11	12 months	Usual care vs TM	2762	pulse oximeter for chronic obstructive pulmonary disease, a glucometer for diabetes, and weighing scales for heart failure.	Broadband Internet	Patient measured vital signs twice weekly. Patients received equipment training	Vital signs reviewed daily by nurse/ physician	-Not reported	Counseling, medication adjustment, referrals, hospital admissions	Motiva system
Takahashi (2012)	Randomized Controlled Trial	USA	November 2009 –July 2011	Patients older than 60 years of age	80 ± 8	12 months	Usual care vs TM	205	scales, blood pressure cuff, glucometer, pulse oximeter, and peak flow	Internet	Patient measured vital signs daily	Vital signs reviewed daily by nurse/ physician	Scheduled	Primary care referral	Intel Health guideTM
Martin-Lesende (2013)	Randomized Controlled Trial	Spain	February 2010 –August 2010	Adult patients	80 ± 9	12 months	Usual care vs TM	58	Conventional devices measuring HR, BP weight, pulse oximeter etc.	Internet and Bluetooth	Patient measured vital signs daily	Vital signs outside range defined by algorithm seen by a nurse	Instantaneous	Primary care referral	
Upatising (2015)	Randomized Controlled Trial	USA	November 2009 –July 2011	Patients older than 60 years of age	80 ± 8	12 months	Usual care vs TM	205	Weight scale, blood pressure cuff, glucometer, and pulse oximeter	Internet	Patient measured vital signs daily	Vital signs reviewed daily by nurse/ physician	Scheduled	Primary care referral	Intel Health guideTM
Kenealy (2015)	Randomized Controlled Trial	New Zealand	September 2010–August 2011	Adult patients	72 [variable IQR]	6 months	Usual care vs TM	171	Weight scale, blood pressure cuff, glucometer, and pulse oximeter	Telephone line	Patient measured vital signs twice weekly. Patients received equipment training	Vital signs reviewed by nurse on weekdays	Scheduled	Patient contacted remotely by nurse, Patient contacted remotely by GP, Nurse visits, GP visits, Secondary care referral	Docobo Health hub

Telemetry (TM), United Kingdom (UK), United States of America (USA). 1Age reported as mean ± standard deviation (SD) or median and Interquartile Range [IQR] of the telemetry group.

Table 2 – Vital signs measures, outcomes and significant results. Parameters: glucose measurement (G), Abbreviations: rhythm (R), electro-cardio-gram (ECG), Impedance (I), peakflow (PF), questionnaires (Q), spirometry (S), weight (W). Clinical impact: usual care (UC), Telemonitoring™, risk ratio (RR), incidence rate ratio (IRR), odds ratio (OR), hazard ratio (HR), confidence Interval (CI), emergency department (ED).

Author	Study Year	Weight	HR	BP	SPO2	Temp	Others	Frequency of monitoring	Outcomes measured	Clinical Impact
Heart-failure										
J. Cleland	2005	X	X	X			R	Twice daily	HospitalizationMortality	Reduction in one year mortality [16% $p=0.032$]Reduction in admission duration [−4 days (95%CI −10 days to +2 days)]
Mortara	2009	X	X	X			Q, ECG	Weekly	Hospitalization Mortality	No difference in hospitalization and mortality
Dar	2009	X	X	X	X		Q	Daily	Hospitalization Time to admission Duration of admission Cost	Reduction in HF emergencies [UC 81%, TM 36%, $p=0.01$] No difference in hospitalisations or cost ($p=0.3$).
Domingo	2011	X	X	X			Q	Daily	Hospitalization Duration of admission	Reduction in admissions with heart failure [67.8% 95%CI 58.2−77.4%, $p=0.01$] Reduction in duration of admissions with heart failure [73.3% 95%CI 64.2−82.4%, $p=0.037$]
Dendale	2011	X	X	X				Daily	HospitalizationMortality Cost	Reduction in mortality [17.5% in UC vs 5% in TM, $p=0.012$] Reduction in heart failure hospitalization [0.42 in UC vs 0.24 in TM, $p=0.056$) Reduction in days lost due to death or hospitalisations [30.2 UC vs 13.1 TM, $p=0.025$]
Vuorinen	2014	X	X	X				Weekly	, Duration of admission Mortality Health care utilization	Increase in cardiology outpatient clinic visits [IRR 3.31 95%CI 2.15−5, $p<0.001$] No effect on duration of admission [IRR 0.812 95%CI 0.52−1.2, $p=0.351$]
Kraai	2015	X		X			Q, ECG	Daily	HospitalizationMortality Cost	Reduction in cardiac outpatient [4 UC vs 2 TM, $p<0.02$] No difference in mortality [HR 1.25 95%CI 0.5−3, $p=0.62$] No effect on readmissions with heart failure [28% in UC vs 27% in TM, $p=0.63$]
Kotooka	2018	X	X	X				Daily	Hospitalization Mortality	No difference in hospitalization [HR 0.79 95%CI 0.47 −1.32, $p=0.37$] No difference in mortality [HR 0.8 95%CI 0.35−1.84, $p=0.614$)
Koehler	2018	X	X	X	X		ECG	Daily	Hospitalization Mortality	Reduction in days lost due to unplanned cardiovascular hospitalization and all-cause mortality [Ratio of weighted averages 0.8 95%CI 0.65 −1.0, $p=0.046$]
Palmieri	2011		X	X	X			3/week	Hospitalization mortality	Decrease in hospitalizations [2.2 in UC vs 0.9 TM, $p<0.01$] No difference in mortality
COPD										
De San Miguel	2013	X	X	X	X	X	Q	Daily	GP & ED visits Hospitalization Duration of admission Cost of care	No difference in hospitalization [17 in UC vs 8 in TM, $p>0.05$] No difference in duration of admission [162 in UC vs 85 in TM, $p>0.05$] No difference in ED visits [11 in UC vs 6 in TM, $p>0.05$]
Pinnock	2013				X		Q	Daily	Time to admission Duration of admission Hospitalization Mortality	No difference in hospitalisations [HR 1.08 95% CI 0.8 −1.45, $p=0.63$] No difference in duration of admission [1.05 95% CI 0.75 −1.48, $p=0.78$]
Pedone	2013		X		X	X		Every 3h	Acute exacerbationsHospitalization Duration of admission	No difference in hospitalization [IRR 0.66 95%CI 0.21 −1.86, $p>0.05$] No difference in duration of admission [6.9 in UC vs 9.7 in TM, p 0.05]

(continued on next page)

Table 2 *(continued)*

Author	Study Year	Weight	HR	BP	SPO2	Temp	Others	Frequency of monitoring	Outcomes measured	Clinical Impact
McDowell	2015		X	X	X		Q	Daily	Hospitalisations GP & ED visits	Insignificant reduction in hospitalisations [Mean difference −0.15 95%CI 0.22 to −0.53, $p=0.4$] Reduction in ED visits [Mean difference −0.19 95%CI 0.25 to −0.63, $p=0.4$] Reduction in GP visits [Mean difference −0.9 95%CI 0.11 to −1.91, $p=0.07$]
Chatwin	2017	X	X	X	X			Daily Heart rate and SPO2, weekly weight and blood pressure	Hospitalisations Home visits GP visits Hospital Visits	Increase in hospitalisations [0.32 in UC vs 0.63 in TM, $p=0.026$] Increase in home visits [0.75 in UC vs 4 in TM, $p<0.001$] No difference in GP visits [5.17 in UC vs 5.75 in TM, $p=0.57$]
Segrelles Calvo	2014		X	X	X		Q, PF	Daily Thrice weekly PEF	ED visit Hospitalization Duration of admission Mortality	Reduction in hospitalizations [33 UC vs 12 TM, $p=0.015$]Reduction in emergency visits [57 UC vs 20 TM, $p=0.001$] Reduction in duration of admission [276 UC vs 105 TM, $p=0.018$]
Ringbæk	2015	X	X		X		S,Q	Pulse oximetry and weight 3×/week (first 4 weeks), then 1×/week. Spirometry 1×/week (first 4 weeks) then once monthly	Hospitalisations Exacerbations	No difference in hospitalisations[0.54 in UC vs 0.55 in TM, $p=0.74$] No difference in duration of admission [5.29 in UC vs 5.35 in TM, $p=0.38$]
Ho	2016	X	X	X	X	X		Daily	Acute exacerbations Time to admission ED visits Hospitalization	Reduction in hospital readmissions [0.68 in UC vs 0.23 in TM, $p=0.002$] Reduction in ER visits [0.91 in UC vs.36 in TM, $p=0.006$] Reduced probability of COPD related readmission [HR 0.42, 95%CI 0.19−0.92, $p=0.026$)
Walker	2018		X	X	X	X	I (forced oscillation technique)	Daily	Time to admission Duration of admission Hospitalization	Reduction in re-hospitalisations [IRR 0.46 95%CI 0.24 −0.87, $p=0.017$] Reduction in duration of admission [4 UC vs 1 TM, $p=0.045$]
Mixed population Finkelstein[1]	2006	X		X	X		S	Twice weekly	Mortality Hospitalization Nursing home admission	Reduction in hospital or nursing admissions [42% UC vs 17% TM, ($p=0.055$) Reduction in mortality [26% in UC, 20% in TM, $p=0.74$]
Steventon[2]	2011	X			X		G, Q	Daily	ED visits Hospitalization Duration of admission Mortality	Reduction in hospital admissions [OR 0.82 95%CI 0.7 −0.97, $p=0.017$], Reduction in mortality [0.54, 95%CI 0.39−0.75, $p<0.001$] Reduction in emergency visits [IRR 0.85, 95%CI 0.73−1, $p=0.044$] Reduction in duration of admission [Mean difference −0.64 days, 95%CI −1.14 to −0.1, $p=0.023$]
Takahashi[3]	2012			X	X		G, S	Daily	ED visits Hospitalization Mortality	No difference in hospitalisations [45 UC vs 53 TM, $p=0.2$}. No difference in emergency visits [29 UC vs 36 TM, $p=0.2$] Increased mortality [4 UC vs 15, $p=0.008$]
Martin-Lesende[4]	2013	X	X	X	X	X	Q	Daily	Hospitalization Duration of admission Mortality	Reduction in hospitalisations [RR 0.66, 95% CI 0.44−0.99, $p=0.033$] Reduction in duration of admission [10.7 UC vs 9 TM, $p=0.89$) Reduction in mortality [8 in UC vs 3 in TM, $p=0.31$]
Upatising[5]	2015	X		X	X		G	Daily	Total standardized cost: inpatient, outpatient and ED	Insignificant reduction in total health care cost by 33% ($p=0.068$)

Table 2 *(continued)*

Author	Study Year	Weight	HR	BP	SPO2	Temp	Others	Frequency of monitoring	Outcomes measured	Clinical Impact
Vitacca[6]	2009				X		Q	Weekly (but variable)	Hospitalisations GP & ED Visits	Reduction in hospitalisations per month [0.22 UC vs 0.14 TM, $p<0.01$] Reduction in GP visits [0.22 UC vs 0.07 TM, $p<0.002$] No difference in emergency room admissions [0.1 UC vs 0.07 TM, $p>0.05$]
Kenealy[7]	2015	X	X	X	X			Daily	Hospitalisations, ED visits,	No difference in hospitalisations ($p=0.15$) or ED visits ($p=0.9$)

Patient populations examined in the studies with mixed population: 1. chronic wound care, HF and COPD, 2. diabetes, HF, COPD, 3. heart disease, COPD, diabetes, stroke, dementia, 4. HF, chronic lung disease, 5. cancer, CHF, COPD, dementia, diabetes, renal insufficiency, stroke, 6. COPD, restrictive lung diseases, amyotrophic lateral sclerosis, neuromuscular disorders, HF, 7. CHF, COPD and diabetes.

Twenty three studies used standard medical devices and manual data entry or modems to monitor the vital signs[21–28,30,31,34–45,47] while two studies used a wearable electronic device for monitoring.[32,46] Details on characteristics of monitoring devices was missing in one study.[48]

Information was transferred through a secure broadband internet connection was in eleven studies[21,22,24,26,27,31,36–38,43,47] whilst cellular communication devices were utilized in five studies[32,35,39,40,46] and communication through a telephone line was used in nine studies.[23,25,28,30,34,41,42,44,45]

Devices in four studies had built in transmission capability via the internet: Two of these were wearable electronic devices (Sweetage™,[32] Wristclinic™[46]); the other two utilized an Intel Health™ Telemonitoring device.[21,22]

Parameters measured

Twenty three studies evaluated tele-monitoring devices while two studies[32,46] reported on the use of wearable electronic device: studies involving telemonitoring utilized between one and five vital signs (Table 2): Heart rate (n=11) and weight (n=14) were the most commonly monitored vital sign in studies on heart failure (n=16) whereas oxygen saturation (n=13) was most commonly monitored in studies on COPD (n=13). Blood pressure was the most measured variable among all the telemonitoring studies (n=20) followed by weight (n=18), heart rate (n=17), oxygen saturation (n=17), electrocardiogram (n=4), temperature (n=3) and spirometry (n=3) (Table 2). Two studies used wearable wrist devices to measure heart rate, temperature, blood pressure, pulse oximetry.[32,46] Forced Oscillation Technique,[46] a non-invasive method that evaluates the resistance and reactance of the respiratory system, was used in COPD patients.

Telemetric measurements were taken at variable intervals: once,[38,43,45] twice[23] or thrice weekly,[33] once daily[21,22,24–28,30,31,35–37,39–42,47] or twice daily.[44] One study had variable monitoring regime.[43] In the two studies using wearable electronic device one study monitored five times a day[32] while the other monitored once daily.[46]

Monitoring with patient questionnaires

Twelve out of 21 selected telemedicine studies utilized a subjective assessment of patient's symptoms in the form of a questionnaire along with the vital signs to anticipate worsening.[24–26,28,30,31,34,40,41,43,45,47] These questionnaires were completed digitally or were communicated verbally by telephone. Out of these twelve, four studies demonstrated a reduction in number of hospitalisations or length of stay.[26,29–31]

Response to abnormal Vital signs

Responses to abnormal vital signs could be in real time/instantaneous or scheduled/intermittent. Full details of the telemonitoring protocol were available for all the studies (Table 1): Protocols in eight studies involved the use of automatic computer algorithms for patient risk assessment.[30,31,36,39,40,44–46] These algorithms were either based on a pre-defined alarm limits for vital signs or a dynamic range based on historical vital signs of the individual patient. Only patients with measurements outside the alarm limits were reviewed by clinical staff. Six of these studies[30,31,36,39,44,46] demonstrated significant reduction in hospitalization and mortality.

In 15 studies, all the data obtained from the patients was monitored regularly by clinical staff, of these, three[26,34,48] showed improved clinical outcomes. Three studies combined both automated algorithms and direct monitoring,[24,27,35] of these one[35] showed statistically significant reduction in hospitalization.

Abnormal vital signs resulted in a number of interventions: lifestyle and/or medication advice, medication review and adjustments, video conferences, primary care referrals, home visits, secondary care referrals and admissions to hospital (Table 1).

Diagnostic groups studied

Ten studies evaluated the impact of telemonitoring in CHF[25,29,35,37–40,44,45,48] but wearable technology was not evaluated. Improvement in chosen clinical outcomes for chronic heart failure patients was associated with the frequency of vital sign monitoring: Five of eight studies that measured vital signs at least daily[29,35,39,44] vs none that used weekly[38,45] monitoring. Weight,[25,29,35,37–40,44,45] heart rate[25,29,35,37–39,44,45,48] and blood pressure[25,29,35,37–40,44,45,48] were monitored in almost all the studies whereas oxygen saturation was measured in only three[25,35,48] of which two studies[35,48] could demonstrate reduced hospitalisations in the intervention group. ECG was monitored in 4 studies[35,40,44,45] out of which two studies showed significant reduction in number of hospital admissions or duration of admissions[35,44] (Table 2).

Nine studies[24,27,28,30,32,36,41,43,46] evaluated the impact of telemonitoring in COPD and two[32,46] assessed the wearable wrist devices

Sweetage™ and Wrist clinic™. In most of these studies patients were monitored daily, and all measured oxygen saturation: one also measured spirometry,[43] one measured peak expiratory flow[30] and one study used Forced Oscillation Technique.[46] Two out of the seven telemonitoring studies[30,36] showed significant reduction in hospitalisations and emergency room visits while only one[46] study using wearable electronic devices could demonstrate improvement. Two of the three studies which showed significant improvement used some measure of lung function for monitoring[30,46] (Table 2).

Seven studies[21–23,26,31,34,42] evaluated the impact of telemonitoring on a general population with a variety of diseases such as COPD, heart failure, diabetes, cancer, dementia, chronic wound care, renal failure, chronic respiratory failure and stroke (Table 2). All studies used conventional devices. Three[26,31,34] showed significant reduction in hospitalisations. The largest clinical trial in this group, with 2762 patients who were followed for a year, showed significant reduction in hospital bed days.[26] Patients with heart failure and COPD were present in all the studies (Table 2).

Clinical outcome measures

Outcomes were compared in parallel groups between monitored and unmonitored patients in 24 studies. The remaining two studies were pre-post-intervention studies.[47,48]

Clinical outcomes in studies of telemonitoring included emergency presentations to primary care, rate of hospital admissions, duration of admission, time to hospital admission, healthcare cost and mortality (Table 2). Four studies used a composite outcome of hospitalizations and mortality.[35,37,40,45] Clinical outcomes in studies of wearable sensors included number of hospitalizations[32] and disease exacerbations,[32] time to admissions,[46] re-hospitalizations[46] and length of stay.[46]

Interventions in 12 studies[24–28,30,32,34,35,37,42,46] were progressively escalated (advice, medication adjustments, home visits, referrals and admissions) based on the severity of vital sign derangements and their symptoms; five of these studies[26,30,34,35,46] demonstrated a statistically significant reduction in hospitalizations and/or mortality. 13[21–23,43–45,47,31,36,38–41] studies utilized a single intervention regardless of severity (medical advice, medication review or referral); five of these studies[31,36,39,44,47] demonstrated statistically significant reduction in hospitalization.

Significant reductions in either number of hospitalizations and/or mortality in the monitored group occurred in only 11 out of 26 studies: five in heart failure patients,[29,35,39,44,48] three in COPD[30,36,46] and three in patients with multiple conditions.[26,31,34]

Discussion

Major findings

This review identified significant gaps in the existing literature. No studies described the use of patient held data on admission to hospital to support decision making about clinical care, admission, or discharge. Vulnerable and high-risk patient groups were excluded from some of the studies, yet these might have been the very patients with most to gain from trend analysis of vital signs available on arrival to hospital. Moreover, despite the availability of an accelerometer on every smart phone, we found no study considered prior mobility for triage decisions.

Limitations

This focused scoping review only examined manuscripts from peer-reviewed journals and included only fully licenced (i.e., FDA or CE marked) devices and no prototypes. We did not include trials that are currently in progress and have not been reported yet. We are unsure how many studies might have been reported outside of peer-reviewed journals in lifestyle or consumer magazines. In most trials, vital signs were recorded infrequently using conventional devices. Only two studies used wearable devices that performed measurements as frequently as every hour and transmitted this data directly to a remote database. Therefore, impact of using continuous monitoring of vital signs with wearable devices could not be appraised. The use of wearables for clinical research might be currently limited by battery life and might increase as battery technology advances.

Interpretation

Telemonitoring has been focused predominantly on patients with two disease groups: COPD and heart failure. Almost all studies that reported statistically significant results used measurements that were performed at least once per day. We found no evidence of use in other patient groups with common chronic physiological abnormalities such as asthma, atrial fibrillation, glomerulonephritis, or liver cirrhosis. Several studies did not include patients with cognitive impairments and those with end-stage disease.

Consumer grade vital sign monitoring has been available for over 15 years and vital signs can be measured by patients even without medical grade sensors.[49] Anecdotal reports about the utility of wearables to identify significant illness have been published,[20,50] but the Apple Watch series 3 linked to an external KardiaBand[51,52] and Apple Watch series 4 are the first consumer device that were licensed as a medical device by the U.S. Food and Drug Administration (FDA) for its ability to record an electro-cardiogram (ECG) to detect rhythm abnormalities.[53,54] Longitudinal monitoring of trends in heart rate have predictive power but the clinical application is far from clear[55,56] and health-economic evaluations of the older generation of tele-medicine devices might not be cost-efficient.[57,58]

Understanding of trends in vital signs is important for the whole patient journey before, during and after assessment in an emergency department[59] or acute medical unit.[60] Algorithms and Artificial Intelligence may bring a new age of safety to healthcare. However, machine learning requires large amounts of data that is current, correct and complete, and the number of patients currently enrolled in studies so far reported may not be sufficient. Wearables have also been suggested as a tool for pre-hospital triage in major disasters[61] and can be used to predict long term health outcomes: A review found only eight studies predicting either long-term mortality or readmissions to hospital.[62] Given the large amount of devices sold the small number of published studies still seems curious.

Clinical implications

It remains to be seen if the participation of patients in their own monitoring is empowering and improves care or creates needless anxiety as patients notice fluctuations on their vital signs that are within the normal range. There are also real concerns around digital inclusion of frail and elderly patients and about equitable access to services for those with limited digital literacy. Although the need to monitor patients remotely has been thrown into sharp focus by the

COVID-19 pandemic,[63,64] the impact of notifications generated by automated systems on workload of already over-stretched clinical teams in primary and secondary care requires further assessment.[65] While intermittent and continuous vital sign monitoring has been a backbone of safe care for patients admitted to hospital[66] or in a clinical prehospital setting,[67] there is currently little literature is available on its use in the community.

Conclusion

There are significant gaps in the peer reviewed literature with important opportunities for future research and development. Despite the possibilities of frequent and continuous measurement of vital signs, most studies used conventional devices for home monitoring. There is little evidence that vital signs recorded by patients are used for decision making by clinicians at the hospital front door; this was true for both consumer and medical devices. Only studies that performed measurements at least once per day found measurable impact on mortality and health-economic metrics. More studies are needed to determine if home measured vitals can improve early detection, timely management and holistic recovery of patients presenting to health services with medical emergencies.

Authors' contribution

Christian Subbe, Jelmer Alsma and Harm Haak were responsible for the conceptualization of the study. Muhammad Hamza and Jelmer Alsma performed the initial acquisition of data. John Kellett, Mikkel Brabrand, Erika F. Christensen, Tim Cooksley, Prabath W.B. Nanayakkara, Hanneke Merten, Bo Schouten, Immo Weichert contributed to analysis and interpretation of data.

Muhammad Hamza Christian Subbe, Jelmer Alsma and John Kellett drafted the initial manuscript. Mikkel Brabrand, Erika F. Christensen, Tim Cooksley, Harm R. Haak, Prabath W.B. Nanayakkara, Hanneke Merten, Bo Schouten, Immo Weichert revised the manuscript critically for important intellectual content.

Muhammad Hamza, Jelmer Alsma, John Kellett, Mikkel Brabrand, Erika F. Christensen, Tim Cooksley, Harm R. Haak, Prabath W.B. Nanayakkara, Hanneke Merten, Bo Schouten, Immo Weichert, Christian Subbe approved the final manuscript.

Funding

No funding was received for the conduct of this scoping review.

Conflict of interest

Chris Subbe has undertaken Consultancy work and acted as a Principal Investigator for Philips Healthcare. Philips Healthcare produces wearable monitoring devices.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

The authors would like to thank the safer@home consortium for helping to crystalize the idea for the paper and for feedback on draft versions.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resplu.2021.100116.

REFERENCES

1. Thornton J. The "virtual wards" supporting patients with covid-19 in the community. BMJ 2020;369, doi:http://dx.doi.org/10.1136/bmj.m2119.
2. Van Der Kluit MJ, Dijkstra GJ, De Rooij SE. The decision-making process for unplanned admission to hospital unveiled in hospitalised older adults: a qualitative study. BMC Geriatr 2018;18:318, doi:http://dx.doi.org/10.1186/s12877-018-1013-y.
3. Emmanuel A, Ismail A, Kellett J. Assessing the need for hospital admission by the Cape Triage discriminator presentations and the simple clinical score. Emerg Med J 2010;27:852–5.
4. Subbe CP, Jishi F, Hibbs RAB. The simple clinical score: a tool for benchmarking of emergency admissions in acute internal medicine. Clin Med J R Coll Phys Lond 2010;10:352–7.
5. Kellett J, Emmanuel A, Deane B. Who will be sicker in the morning? Changes in the Simple Clinical Score the day after admission and the subsequent outcomes of acutely ill unselected medical patients. Eur J Intern Med 2011;22:375–81, doi:http://dx.doi.org/10.1016/j.ejim.2011.03.005.
6. Bleyer AJ, Vidya S, Russell GB, et al. Longitudinal analysis of one million vital signs in patients in an academic medical center. Resuscitation 2011;82:1387–92, doi:http://dx.doi.org/10.1016/j.resuscitation.2011.06.033.
7. Chang CY, Abujaber S, Pany MJ, Obermeyer Z. Are vital sign abnormalities associated with poor outcomes after emergency department discharge? Acute Med 2019;18:88–95.
8. Jones M. NEWSDIG: the national early warning score development and implementation group. Clin Med J R Coll Phys Lond 2012;12:501–3.
9. Brink A, Alsma J, Fortuin AW, et al. Prediction models for mortality in adult patients visiting the Emergency Department: a systematic review. Acute Med 2019;18:171–83.
10. Eccles SR, Subbe C, Hancock D, Thomson N. CREWS: improving specificity whilst maintaining sensitivity of the National Early Warning Score in patients with chronic hypoxaemia. Resuscitation 2014;85:109–11.
11. Kawashiro N, Kasanuki H, Ogawa H, Matsuda N, Hagiwara N. Heart Institute of Japan – Department of Cardiology (HIJC) Investigators. Clinical characteristics and outcome of hospitalized patients with congestive heart failure: results of the HIJC-HF registry. Circ J 2008;72:2015–20, doi:http://dx.doi.org/10.1253/circj.cj-08-0323.
12. Subbe CP, Duller B, Bellomo R. Effect of an automated notification system for deteriorating ward patients on clinical outcomes. Crit Care 201721:, doi:http://dx.doi.org/10.1186/s13054-017-1635-z.
13. Subbe CP, Jones S. Predicting speed at traffic lights-the problem with static assessments of frailty. Age Ageing 2015;44:180–1, doi:http://dx.doi.org/10.1093/ageing/afu204.
14. Brekke IJ, Puntervoll LH, Pedersen PB, Kellett J, Brabrand M. The value of vital sign trends in predicting and monitoring clinical deterioration: a systematic review. PLOS ONE 201914:, doi:http://dx.doi.org/10.1371/journal.pone.0210875.

15. Newzoo Global Esports Market Report 2019 | Light Version | Newzoo. Newzoo 2019. https://newzoo.com/insights/trend-reports/newzoo-global-mobile-market-report-2019-light-version/ [accessed 17 July 2020].
16. Institute of Medicine (U.S.). Crossing the quality chasm: a new health system for the 21st century. Washington, D.C: National Academy Press; 2001.
17. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19–32.
18. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. Implement Sci 2010;5:69, doi:http://dx.doi.org/10.1186/1748-5908-5-69.
19. Ringwald M, Crich A, Beysard N. Smart watch recording of ventricular tachycardia: case study. Am J Emerg Med 202038:, doi:http://dx.doi.org/10.1016/j.ajem.2019.10.040 849.e3–e5.
20. Weichert I. "My watch kept on alarming all night about my heart rate": diagnosis of asymptomatic atrial fibrillation with fast ventricular response in a patient with a recent TIA as the result of a smartwatch alarm. Oxford Med Case Rep 2019 2019, doi:http://dx.doi.org/10.1093/omcr/omz014.
21. Upatising B, Wood DL, Kremers WK, et al. Cost comparison between home telemonitoring and usual care of older adults: a randomized trial (Tele-ERA). Telemed e-Health 2015;21:3–8, doi:http://dx.doi.org/10.1089/tmj.2014.0021.
22. Takahashi PY, Pecina JL, Upatising B, et al. A randomized controlled trial of telemonitoring in older adults with multiple health issues to prevent hospitalizations and emergency department visits. Arch Intern Med 2012;172:773–9, doi:http://dx.doi.org/10.1001/archinternmed.2012.256.
23. Finkelstein SM, Speedie SM, Potthoff S. Home telehealth improves clinical outcomes at lower cost for home healthcare. Telemed J e-Health 2006;12:128–36, doi:http://dx.doi.org/10.1089/tmj.2006.12.128.
24. Pinnock H, Hanley J, McCloughan L, et al. Effectiveness of telemonitoring integrated into existing clinical services on hospital admission for exacerbation of chronic obstructive pulmonary disease: researcher blind, multicentre, randomised controlled trial. BMJ 2013;347:f6070, doi:http://dx.doi.org/10.1136/bmj.f6070.
25. Dar O, Riley J, Chapman C, et al. A randomized trial of home telemonitoring in a typical elderly heart failure population in North West London: results of the Home-HF study. Eur J Heart Fail 2009;11:319–25.
26. Steventon A, Bardsley M, Billings J, et al. Effect of telehealth on use of secondary care and mortality: findings from the Whole System Demonstrator cluster randomised trial. BMJ 2012344:, doi:http://dx.doi.org/10.1136/bmj.e3874 e3874.
27. Chatwin M, Hawkins G, Panicchia L, et al. Randomised crossover trial of telemonitoring in chronic respiratory patients (TeleCRAFT trial). Thorax 2016;71:305–11, doi:http://dx.doi.org/10.1136/thoraxjnl-2015-207045.
28. McDowell JE, McClean S, FitzGibbon F, Tate S. A randomised clinical trial of the effectiveness of home-based health care with telemonitoring in patients with COPD. J Telemed Telecare 2015;21:80–7, doi:http://dx.doi.org/10.1177/1357633X14566575.
29. Domingo M, Lupón J, González B, et al. Telemonitorización no invasiva en pacientes ambulatorios con insuficiencia cardiaca: Efecto en el número de hospitalizaciones, días de ingreso y calidad de vida. Estudio CARME (CAtalan Remote Management Evaluation). Rev Esp Cardiol 2011;64:277–85, doi:http://dx.doi.org/10.1016/j.recesp.2010.10.032.
30. Calvo GS, Gómez-Suárez C, Soriano JB, et al. A home telehealth program for patients with severe COPD: the PROMETE study. Respir Med 2014;108:453–62, doi:http://dx.doi.org/10.1016/j.rmed.2013.12.003.
31. Martín-Lesende I, Orruño E, Bilbao A, et al. Impact of telemonitoring home care patients with heart failure or chronic lung disease from primary care on healthcare resource use (the TELBIL study randomised controlled trial). BMC Health Serv Res 2013;13:118, doi:http://dx.doi.org/10.1186/1472-6963-13-118.
32. Pedone C, Chiurco D, Scarlata S, Incalzi RA. Efficacy of multiparametric telemonitoring on respiratory outcomes in elderly people with COPD: a randomized controlled trial. BMC Health Serv Res 2013;13:82, doi:http://dx.doi.org/10.1186/1472-6963-13-82.
33. Palmieri V, Pezzullo S, Lubrano V, et al. Telemetria per il controllo domiciliare della pressione arteriosa, della frequenza cardiaca e della saturimetria di ossigeno nello scompenso cardiaco: Impatto sulle ospedalizzazioni in un contesto non sperimentale. G Ital Cardiol 2011;12:829–36, doi:http://dx.doi.org/10.1714/996.10828.
34. Vitacca M, Bianchi L, Guerra A, et al. Tele-assistance in chronic respiratory failure patients: a randomised clinical trial. Eur Respir J 2009;1, doi:http://dx.doi.org/10.1183/09031936.00005608 Al-Khat:411-8.
35. Koehler F, Koehler K, Deckwart O, et al. Efficacy of telemedical interventional management in patients with heart failure (TIM-HF2): a randomised, controlled, parallel-group, unmasked trial. Lancet 2018;392:1047–57, doi:http://dx.doi.org/10.1016/S0140-6736(18)31880-4.
36. Ho TW, Huang CT, Chiu HC, et al. Effectiveness of telemonitoring in patients with chronic obstructive pulmonary disease in Taiwan-a randomized controlled trial. Sci Rep 2016;6:23797, doi:http://dx.doi.org/10.1038/srep23797.
37. Kotooka N, Kitakaze M, Nagashima K, et al. The first multicenter, randomized, controlled trial of home telemonitoring for Japanese patients with heart failure: home telemonitoring study for patients with heart failure (HOMES-HF). Heart Vessels 2018;33:866–76.
38. Vuorinen A-L, Leppänen J, Kaijanranta H, et al. Use of home telemonitoring to support multidisciplinary care of heart failure patients in Finland: randomized controlled trial. J Med Internet Res 201416:e282.
39. Dendale P, De Keulenaer G, Troisfontaines P, et al. Effect of a telemonitoring-facilitated collaboration between general practitioner and heart failure clinic on mortality and rehospitalization rates in severe heart failure: the TEMA-HF 1 (TElemonitoring in the MAnagement of Heart Failure) study. Eur J Heart Fail 2011;14:333–40.
40. Kraai I, de Vries A, Vermeulen K, et al. The value of telemonitoring and ICT-guided disease management in heart failure: results from the IN TOUCH study. Int J Med Inform 2015;85:53–60.
41. De San Miguel K, Smith J, Lewin G. Telehealth remote monitoring for community-dwelling older adults with chronic obstructive pulmonary disease. Telemed e-Health 2013;19:652–7, doi:http://dx.doi.org/10.1089/tmj.2012.0244.
42. Kenealy TW, Parsons MJG, Rouse APB, et al. Telecare for diabetes, CHF or COPD: effect on quality of life, hospital use and costs. A randomised controlled trial and qualitative evaluation. PLOS ONE 201510:, doi:http://dx.doi.org/10.1371/journal.pone.0116188 e0116188.
43. Ringbæk T, Green A, Laursen LC, Frausing E, Brøndum E, Ulrik CS. Effect of tele health care on exacerbations and hospital admissions in patients with chronic obstructive pulmonary disease: a randomized clinical trial. Int J COPD 2015;10:1801–8, doi:http://dx.doi.org/10.2147/COPD.S85596.
44. Cleland JGF, Louis AA, Rigby AS, Janssens U, Balk AHMM. Noninvasive home telemonitoring for patients with heart failure at high risk of recurrent admission and death: the Trans-European Network-Home-Care Management System (TEN-HMS) study. J Am Coll Cardiol 2005;45:1654–64.
45. Mortara A, Pinna GD, Johnson P, et al. Home telemonitoring in heart failure patients: the HHH study (Home or Hospital in Heart Failure). Eur J Heart Fail 2009;11:312–8.
46. Walker PP, Pompilio PP, Zanaboni P, et al. Telemonitoring in Chronic Obstructive Pulmonary Disease (CHROMED). A randomized clinical trial. Am J Respir Crit Care Med 2018;198:620–8, doi:http://dx.doi.org/10.1164/rccm.201712-2404OC.
47. Domingo M, Lupón J, González B, et al. Noninvasive remote telemonitoring for ambulatory patients with heart failure: effect on number of hospitalizations, days in hospital, and quality of life. CARME (CAtalan Remote Management Evaluation) Study. Rev Esp Cardiol 2011;64:277–85, doi:http://dx.doi.org/10.1016/j.recesp.2010.10.032.

48. Palmieri V, Pezzullo S, Lubrano V, et al. Telemetry for home control of blood pressure, heart rate and oxygen saturimetry in heart failure: impact on hospitalizations in a non-experimental context. G Ital Cardiol 2011;12:829–36, doi:http://dx.doi.org/10.1714/996.10828.
49. Nakitende I, Namujwiga T, Dunsmuir D, Ansermino JM, Wasingya-Kasereka L, Kellett J. Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission. Acute Med 202019:.
50. Hwang J, Kim J, Choi K-J, Cho MS, Nam G-B, Kim Y-H. Assessing accuracy of wrist-worn wearable devices in measurement of paroxysmal supraventricular tachycardia heart rate. Korean Circ J 2019;49:437, doi:http://dx.doi.org/10.4070/kcj.2018.0323.
51. Wasserlauf J, You C, Patel R, Valys A, Albert D, Passman R. Smartwatch performance for the detection and quantification of atrial fibrillation. Circ Arrhythm Electrophysiol 2019;12:e006834, doi:http://dx.doi.org/10.1161/CIRCEP.118.006834.
52. Rajakariar K, Koshy AN, Sajeev JK, Nair S, Roberts L, Teh AW. Accuracy of a smartwatch based single-lead electrocardiogram device in detection of atrial fibrillation. Heart 2020;106:665–70, doi:http://dx.doi.org/10.1136/heartjnl-2019-316004.
53. Isakadze N, Martin SS. How useful is the smartwatch ECG? Trends Cardiovasc Med 2020;30:442–8, doi:http://dx.doi.org/10.1016/j.tcm.2019.10.010.
54. Perez MV, Mahaffey KW, Hedlin H, et al. Large-scale assessment of a smartwatch to identify atrial fibrillation. N Engl J Med 2019;381:1909–17, doi:http://dx.doi.org/10.1056/NEJMoa1901183.
55. Achten J, Jeukendrup AE. Heart rate monitoring: applications and limitations. Sport Med 2003;33:517–38, doi:http://dx.doi.org/10.2165/00007256-200333070-00004.
56. Lutz J, Memmert D, Raabe D, Dornberger R, Donath L. Wearables for integrative performance and tactic analyses: opportunities, challenges, and future directions. Int J Environ Res Public Health 202017:, doi:http://dx.doi.org/10.3390/ijerph17010059.
57. Lilholt PH, Udsen FW, Ehlers L, Hejlesen OK. Telehealthcare for patients suffering from chronic obstructive pulmonary disease: effects on health-related quality of life: Results from the Danish? € TeleCare North' cluster-randomised trial. BMJ Open 20177:, doi:http://dx.doi.org/10.1136/bmjopen-2016-014587.
58. Udsen FW, Lilholt PH, Hejlesen O, Ehlers L. Cost-effectiveness of telehealthcare to patients with chronic obstructive pulmonary disease: results from the Danish TeleCare North' cluster-randomised trial. BMJ Open 20177:, doi:http://dx.doi.org/10.1136/bmjopen-2016-014616.
59. Roland B, Nickel Christian H. The last decade of symptom-oriented research in emergency medicine: triage, work-up, and disposition. Swiss Med Wkly 2019;149:41–2, doi:http://dx.doi.org/10.4414/smw.2019.20141.
60. Nannan Panday RS, Subbe CP, van Galen LS, et al. Changes in vital signs post discharge as a potential target for intervention to avoid readmission. Acute Med 2018;17:77–82.
61. Kim D, You S, So S, et al. A data-driven artificial intelligence model for remote triage in the prehospital environment. PLOS ONE 201813:, doi:http://dx.doi.org/10.1371/journal.pone.0206006.
62. Burnham JP, Lu C, Yaeger LH, Bailey TC, Kollef MH. Using wearable technology to predict health outcomes: a literature review. J Am Med Informatics Assoc 2018;25:1221–7, doi:http://dx.doi.org/10.1093/jamia/ocy082.
63. Manta C, Jain SS, Coravos A, Mendelsohn D, Izmailova ES. An evaluation of biometric monitoring technologies for vital signs in the era of COVID-19. Clin Transl Sci 2020, doi:http://dx.doi.org/10.1111/cts.12874.
64. Shah S, Majmudar K, Stein A, et al. Novel use of home pulse oximetry monitoring in COVID-19 patients discharged from the emergency department identifies need for hospitalization. Acad Emerg Med 2020;27:681–92, doi:http://dx.doi.org/10.1111/acem.14053.
65. Subbe CP, Duller B. Continuous monitoring of respiratory rate on general wards what might the implications be for clinical practice? Acute Med 2018;17:5–9.
66. Alam N, Hobbelink EL, van Tienhoven AJ, van de Ven PM, Jansma EP, Nanayakkara PWB. The impact of the use of the Early Warning Score (EWS) on patient outcomes: a systematic review. Resuscitation 2014;85:587–94, doi:http://dx.doi.org/10.1016/j.resuscitation.2014.01.013.
67. Williams TA, Tohira H, Finn J, Perkins GD, Ho KM. The ability of early warning scores (EWS) to detect critical illness in the prehospital setting: a systematic review. Resuscitation 2016;102:35–43, doi:http://dx.doi.org/10.1016/j.resuscitation.2016.02.011.